

## PHL 1811: The Local Prototype of the Lineless High- $z$ SDSS QSOs

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**Abstract.** In the SDSS, several unusual QSOs have been discovered that have very blue rest-frame UV spectra but no discernible emission lines. Their UV spectra strongly resemble that of the newly discovered quasar PHL 1811 ( $z = 0.192$ ;  $M_V = -25.9$ ).

With magnitudes of  $B = 14.4$  and  $R = 14.1$ , PHL 1811 is the second brightest quasar known with  $z > 0.1$  after 3C 273. Optically it is classified as a Narrow-line Seyfert 1 galaxy (NLS1). Objects of this class are generally strong soft X-ray emitters, but a BeppoSAX observation of PHL 1811 showed that it is anomalously X-ray weak. The inferred  $\alpha_{ox}$  was 1.9–2.1, much steeper than the nominal value of 1.6 for quasars of this optical luminosity, and comparable to the X-ray weakest quasars. Follow-up *Chandra* observations reveal a variable, unabsorbed X-ray spectrum and confirm that it is intrinsically X-ray weak.

*HST* STIS spectra of PHL 1811 reveal a very blue continuum with little evidence for absorption or scattering intrinsic to the quasar. High-ionization lines are very weak; C IV has an equivalent width of only  $\sim 5\text{\AA}$ . Neither forbidden nor semiforbidden emission lines are detected. Fe II is the dominant line emission in the UV. High metallicity is implied by the large Fe II to Mg II ratio and relatively strong N V. Low-ionization emission lines of Al III, Na I D, and Ca II H & K are present, implying high optical depth.

We demonstrate that the emission-line properties of PHL 1811 are a direct consequence of the UV-peaked continuum and weak X-ray emission. We propose that these properties are a consequence of high accretion rate, which powers the UV emission from an optically thick accretion disk, while suppressing the formation of a hot corona. This is an extreme case of the same mechanism which is thought to be responsible for luminous NLS1s. Based on the similarity between PHL 1811 and the lineless SDSS

quasars, we propose that the lineless quasars discovered in the SDSS are the high- $z$  counterparts of local high-luminosity NLS1s.

## 1. Introduction

In the Sloan Digital Sky Survey, a number of high redshift quasars have been discovered that are remarkable for their lack of emission lines. A detailed study of one of these objects, SDSSp J153259.96–003944.1 (hereafter referred to as SDSS J1532–0039) was presented by Fan et al. 1999. The optical spectrum, redward of 6800 Å, is a featureless blue power-law continuum; there are no emission lines. Blueward of 6800 Å, there are features due to Ly $\alpha$  absorption that lead to a redshift estimate of 4.52. Featureless continua are frequently found in Bl Lac objects. However, SDSS J1532–0039 does not appear to have other characteristic properties of Bl Lac objects: it was not detected in a deep radio observation, doesn't vary in the optical, and was not found to be optically polarized. Follow-up observations with *Chandra* failed to detect the quasar, indicating an  $\alpha_{ox} > 1.74$ <sup>1</sup>. This steep  $\alpha_{ox}$  makes it moderately X-ray weak (Vignali et al. 2001).

PHL 1811 is a luminous narrow-line quasar that was rediscovered in the VLA FIRST survey (Leighly et al. 2000). It is a very bright ( $B = 14.4$ ,  $R = 14.1$ ), nearby ( $z = 0.192$ ) object, well away from the Galactic plane, so it was surprising that it was not detected in the ROSAT All Sky Survey. Two *Chandra* observations show that it is X-ray weak, with inferred  $\alpha_{ox}$  between 1.9 and 2.1, much steeper than for a typical quasar of this luminosity (1.6; Wilkes et al. 1994). The *HST* spectrum is unusual in that it is dominated by Fe II, and there are no prominent broad emission lines. We thought that the X-ray weakness and the lack of broad emission lines suggest a similarity to SDSS J1532–0039.

## 2. PHL 1811 and the High- $z$ QSOs

The *HST* STIS observation of PHL 1811 was performed 2001 December 3 and the two *Chandra* observations were performed 2001 December 5 and 17. Figure 1 shows the spectral energy distribution of PHL 1811. The steep  $\alpha_{ox}$  show that PHL 1811 was X-ray weak compared with typical quasar of its luminosity. It appears to be intrinsically X-ray weak, rather than absorbed, because it is variable between two observations twelve days apart, a fact that rules out the possibility that the central engine is absorbed and we observe scattered X-rays. Furthermore, the spectral index is nominal for a NLS1 ( $\Gamma \sim 2.25$ ), rather than flat as it might be if it were absorbed. The details of these observations will be presented in Leighly, Halpern & Jenkins, in preparation.

The three high- $z$  lineless quasars that we considered were SDSS J1532–0039 ( $z=4.62$ ; Fan et al. 1999) and two reported by Anderson et al. 2000 (SDSS J1302+0030 and SDSS J1442+0110;  $z=4.5$  and  $z=4.56$ , respectively). Since the

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<sup>1</sup> $\alpha_{ox}$  is defined as the point-to-point slope between 2500 Å and 2 keV.

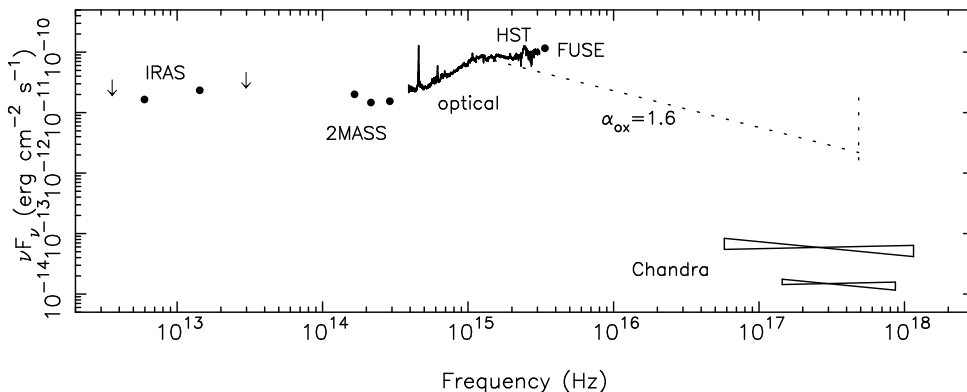


Figure 1. The spectral energy distribution of PHL 1811. The observed  $\alpha_{ox}$  are 1.9 and 2.1; the location of  $\alpha_{ox} = 1.6$ , the typical value for a quasar of this luminosity, is shown.

time that these were reported, apparently a number of others have been discovered (see the contribution by Collinge, these proceedings). Figure 2 shows a comparison of the PHL 1811 UV spectrum, shifted to  $z=4.5$ , with the SDSS spectrum of SDSS J1302+0039. The Keck spectrum of SDSS J1532–0039 published by Fan et al. 1999 has a much better signal-to-noise ratio. To accentuate the contrast between these objects and typical quasars, we also show the Francis et al. (1991) LBQS quasar compilation spectrum shifted to  $z=4.77$ , and the SDSS spectrum of an arbitrarily-chosen high-redshift quasar.

### 3. Discussion and Conclusions

In this contribution, we discuss the similarity between the UV spectrum of PHL 1811 and the spectra of several high- $z$  lineless quasars discovered in the SDSS, and propose that the physical cause of their spectra is the same. At the same time, we acknowledge that the SDSS is quite likely to find lineless quasars whose spectra have a different origin; for example, they may be Bl Lac objects.

If it is true that these spectra are a result of the same phenomenon, what are the potential implications? Because of their steep X-ray spectra and high amplitude X-ray variability, it has been proposed that NLS1s are characterized by a high accretion rate (e.g., Leighly 1999 and references therein). Since emission-line widths should depend on the black hole mass (Laor 2000), luminous NLS1s should have exceptionally high accretion rates compared with their Eddington value. It is important to understand the accretion rate in high redshift objects, as luminous quasars have large black holes, and in order to grow large in the short amount of time implied by the high redshift, they should be accreting at a rapid rate. Naturally, people are searching for a connection between high redshift quasars and NLS1s (e.g., Mathur 2000), although the evidence so far is mixed (Constantin et al. 2002). Based on the similarities between PHL 1811 and the high- $z$  lineless quasars, we suggest that they are the early Universe counterparts of luminous Narrow-line Seyfert 1 galaxies.

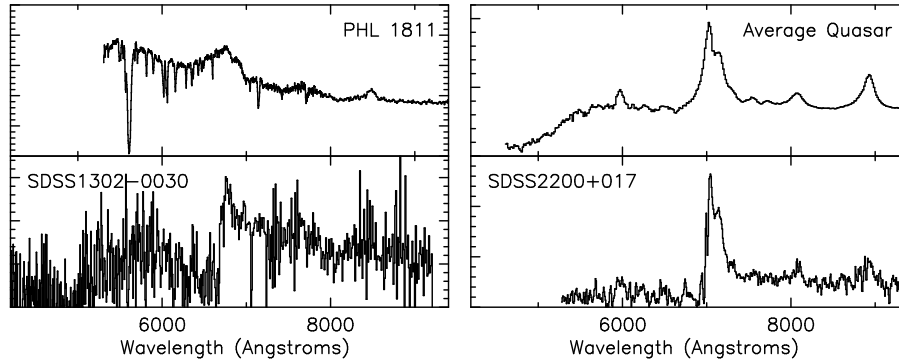


Figure 2. *Left:* The top panel shows PHL 1811, shifted to a redshift of 4.5. The bottom panel shows the SDSS spectrum of one of the high- $z$  lineless quasars. The similarity can be seen, if one takes in to account the difference in signal-to-noise ratio and the presence of Ly $\alpha$  absorption in the high redshift quasar. *Right:* For comparison, the top panel shows the LBQS quasar compilation spectrum from Francis et al. 1991 shifted to  $z=4.77$ , and the bottom panel shows arbitrarily chosen SDSS high redshift quasar SDSS J2200+017.

What causes the weak emission lines? In PHL 1811, the higher-ionization emission lines are probably weak because the continuum is very soft overall. Such a soft continuum can produce copious H<sup>0</sup> and Fe<sup>+</sup> ions, but few higher ionization species. Also, the equivalent widths of the lines will appear small against the strong, blue optical/UV continuum.

## References

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